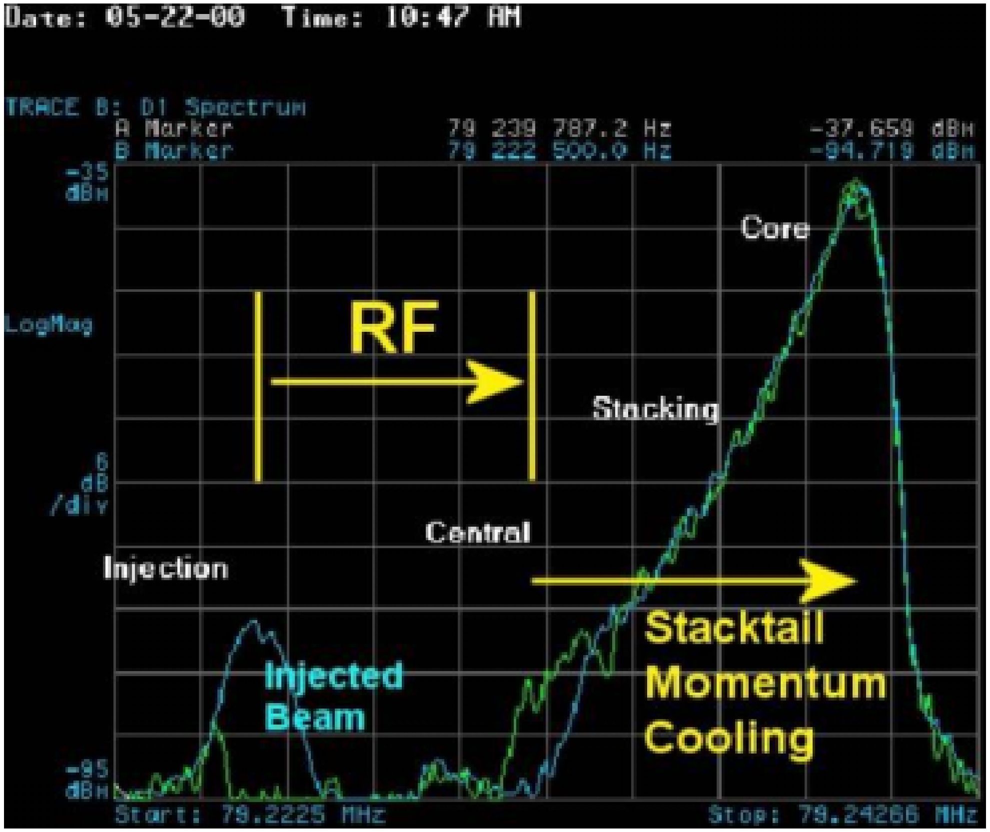
Stochastic Cooling for Run IIb

- Upgrade to handle increased flux
- Design Goals
  - ⇒ flux 80 mA/hour
  - ⇒ Recycler cooling requires $\leq$ 10 eV-sec, 15 π every 15 minutes
- Assumptions:
  - ⇒ Recycler final repository for anti-protons
    - » Stochastic cooling performance degrades with increasing density
    - » Electron cooling performance improves with increasing density
  - ⇒ Optimize for maximum flux
    - » Not maximum momentum density!
  - ⇒ Frequent transfers from Accumulator to Recycler (<30 minutes between transfers)
  - ⇒ Dependent upon incoming longitudinal phase space

Stacking terminology

- Stacking cycle:
  - ⇒ Accelerate to 120 GeV in MI
  - ⇒ Extract to target
  - ⇒ Transport 8 GeV to Debuncher
  - ⇒ Debunch and stochastically cool
  - ⇒ Inject beam into Accumulator
  - ⇒ RF decelerate to deposition orbit
  - ⇒ ~2 sec cycle
- Stacktail cooling moves beam to core



Longitudinal Phase Space

From MI to Debuncher

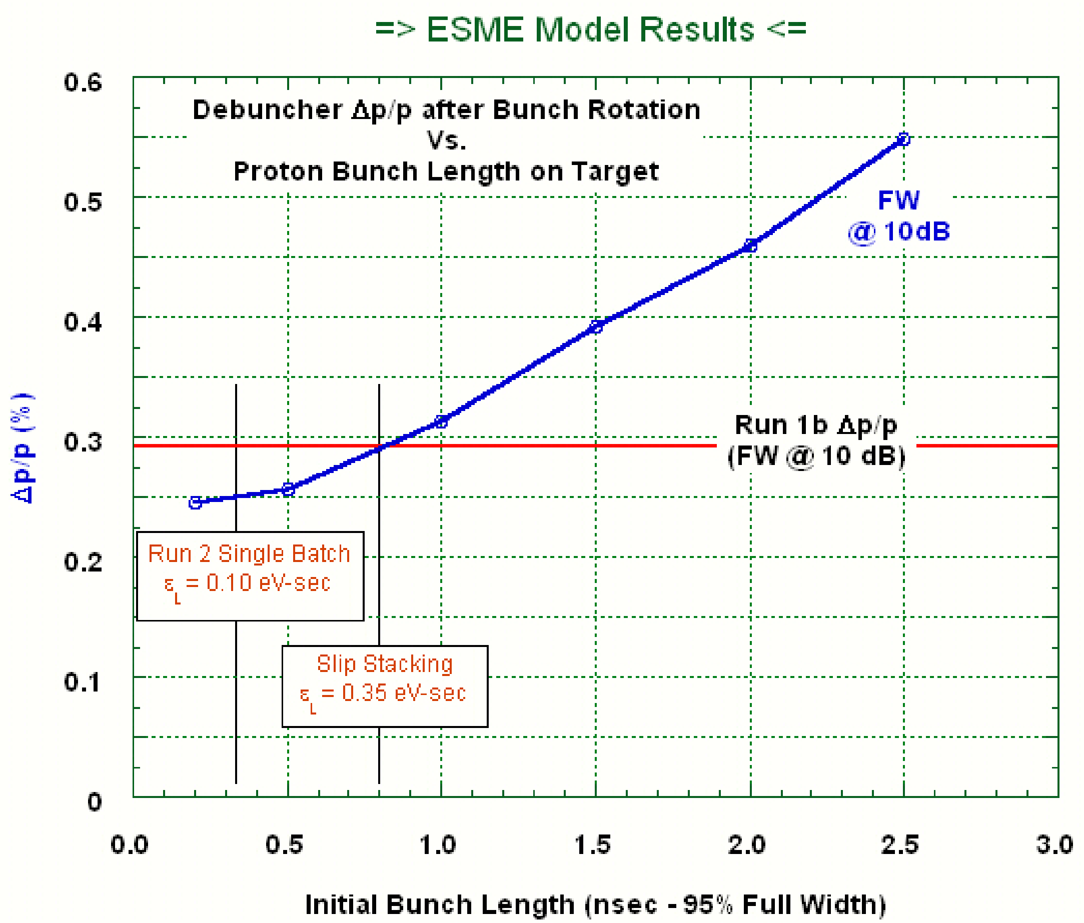
- Slip stacking at 8 GeV: 0.3 eV-sec
- At 120 GeV: 0.35 eV-sec
- ESME simulation of MI Bunch rotation with 0.35 eV-sec:
  - ⇒ Δt = 809 psec (95%)
  - ⇒ $^{\Delta E}/_{E}$ = 0.185% (95% $^{1}/_{2}$ width)
- Beam transport after target:
  - ⇒ ±2% acceptance into Debuncher

Debuncher to Accumulator

- Debuncher Bunch Rotation:
  - ⇒ $^{\Delta E}/_{E}$ = 0.134% (95% $^{1}/_{2}$ width)
  - ⇒ ΔE = 12 MeV
- Debuncher Cooling Upgrades for Run IIa designed to meet IIb goals
- Momentum Cooling Models:
  - ⇒ Moment method calculations (which agree well with simulation model)
  - ⇒ Predict 6 MeV half width
- ESME simulations of RF deceleration preserve width

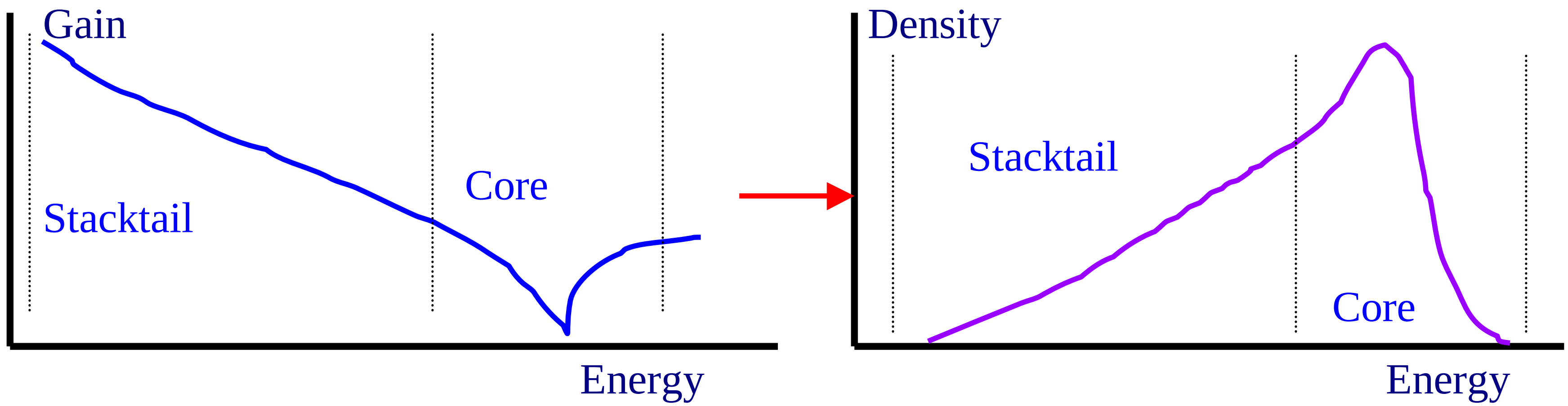
Debuncher Bunch Rotation

Momentum width in Debuncher after bunch rotation not too dependent upon MI longitudinal emittance -- dominated by non-linear rotation in Debuncher



Stochastic Stacking

- Simon van Der Meer solution:
  - ⇒ Constant Flux: $\frac{\partial \psi}{\partial t} = \text{constant}$
  - ⇒ Solution: $\frac{\partial \psi}{\partial E} = \frac{\psi}{E_d}$, where E_d characteristic of design $\psi = \psi_0 \exp\left[\frac{(E - E_i)}{E_d}\right]$
  - ⇒ Exponential Density Distribution generated by Exponential Gain Distribution
  - ⇒ Max Flux = $(W^2|\eta|E_d)/(f_0 p \ln(2))$



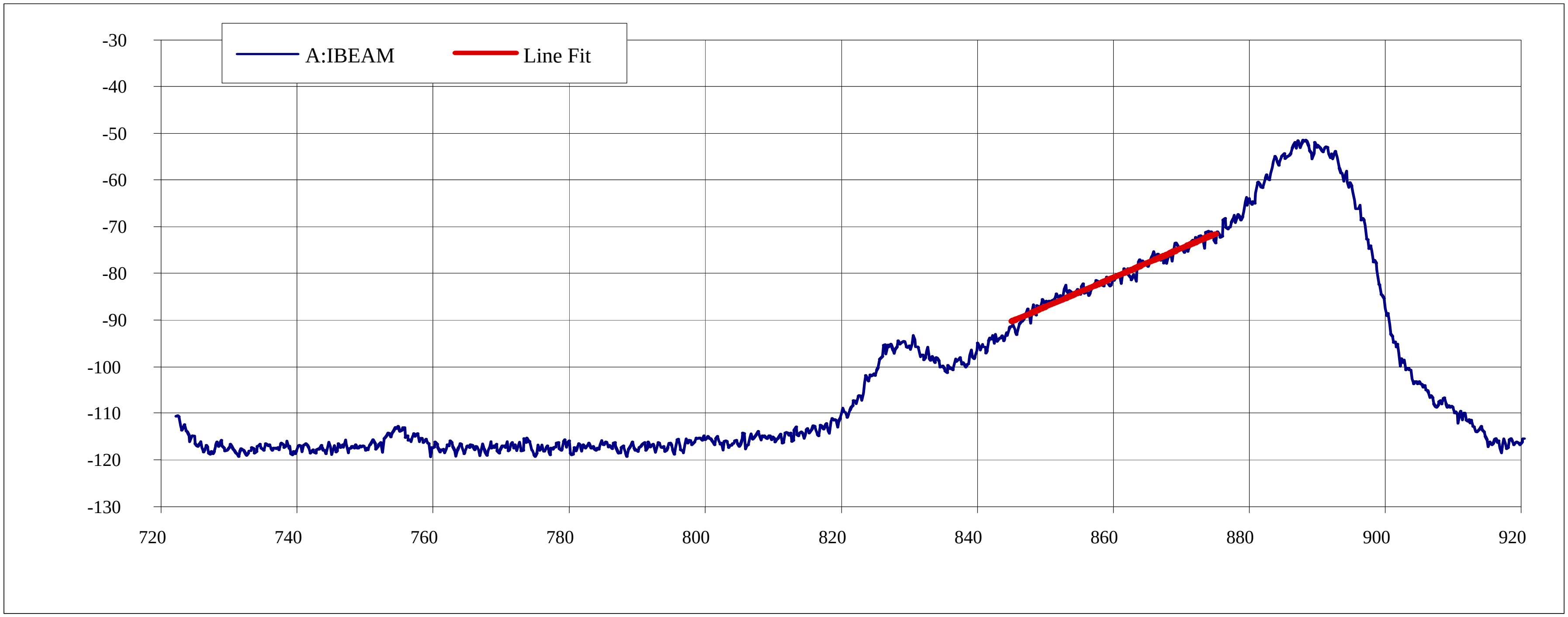
Using log scales on vertical axis

Paul Derwent
7-Dec-01

Flux for current stacktail

- Fit in stacktail region
- Calculate maximum flux based on slope
  - ⇒ 2-4 GHz bandwidth
  - ⇒ $\eta = 0.012$

⇒ 37.5 ± 2.5 mA/hour
⇒ Stack rate ~3 mA/hour
⇒ Data of 1 Aug 01
⇒ Achieved 10 mA/hour about 2 weeks later



Creating Exponential Gain Distribution

- Current intercepted by pickup

$$I = \frac{I_{beam}}{\pi}\left\{\tan^{-1}\left[\sinh\left(\frac{\pi}{d}\left(\Delta x + \frac{w}{2}\right)\right)\right] - \tan^{-1}\left[\sinh\left(\frac{\pi}{d}\left(\Delta x - \frac{w}{2}\right)\right)\right]\right\}$$

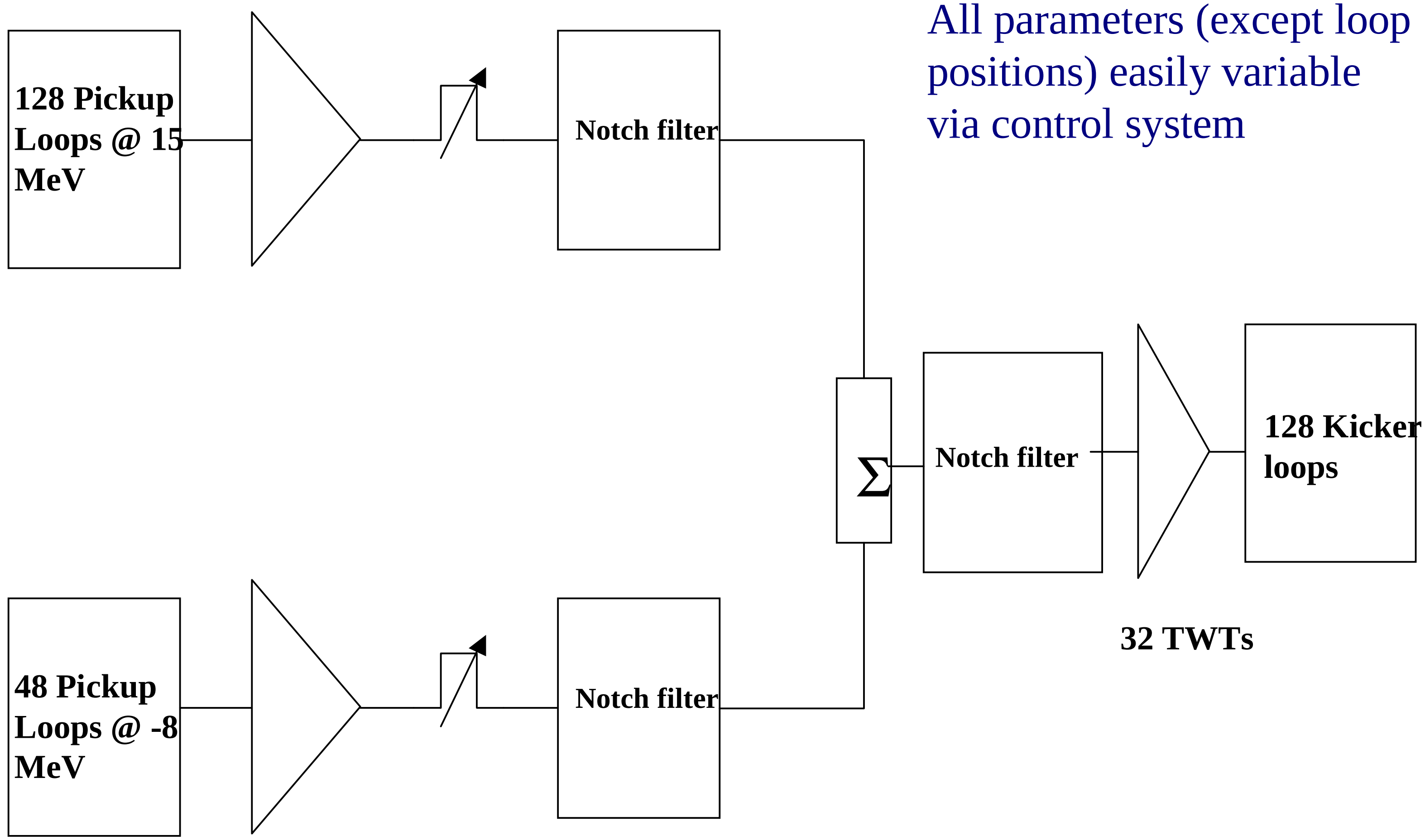
$$\approx \frac{I_{beam}}{\pi}\exp\left(-\frac{\pi\Delta x}{d}\right) \text{ for large } \Delta x$$

- Locate pickups in region of high dispersion
- As particles at different energies have different flight times but electronics delays constant

$\Rightarrow$ Location of pickups, relative gain, relative phase to give proper gain shape

Schematic diagram of stacktail electronics

All parameters (except loop positions) easily variable via control system

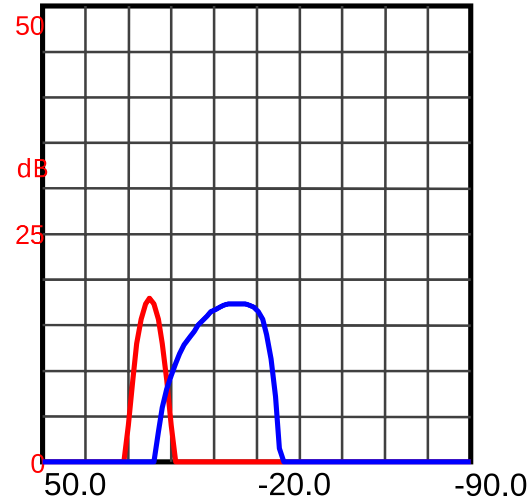


Design Goals, Specifications and Challenges

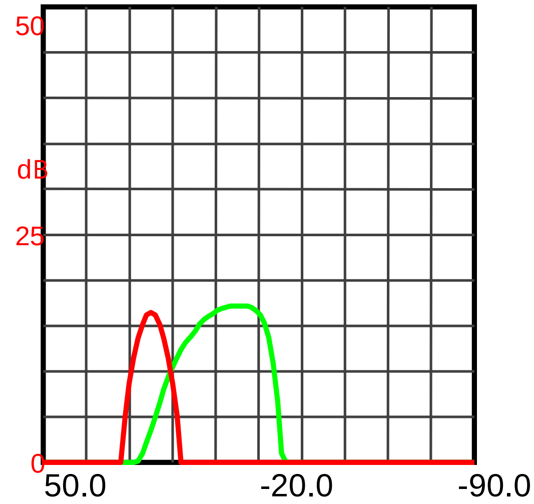
- Goals:
  - ⇒ Input flux of 80 mA/hour
  - ⇒ 30 minutes
  - ⇒ >95% efficiency
- Specifications:
  - ⇒ 2 second cycle time (slip stacking and NUMI)
  - ⇒ 6 MeV bucket height at h=84
- Challenges:
  - ⇒ Finite momentum aperture:
    - » constant flux has to be ‘stopped’ and accumulated at some point
    - » Maximum density
  - ⇒ Transient input:
    - » Pulses every 2 seconds
    - » Move beam off deposition orbits

Input Longitudinal Phase Space

- Moving beam off deposition orbit depends on:
  - ⇒ Gain: more efficient at higher gain
  - ⇒ Cycle time: more efficient with longer cycle time
  - ⇒ Beam width: more efficient with smaller width (assuming completely full buckets)
- Constraints:
  - ⇒ Gain: power and matching
  - ⇒ Cycle time: longer cycle, less total flux
  - ⇒ Beam width: Debuncher cooling performance



6 MeV width



8 MeV width

Gain Constraints

- Match stacktail gain to core gain to preserve gain slope

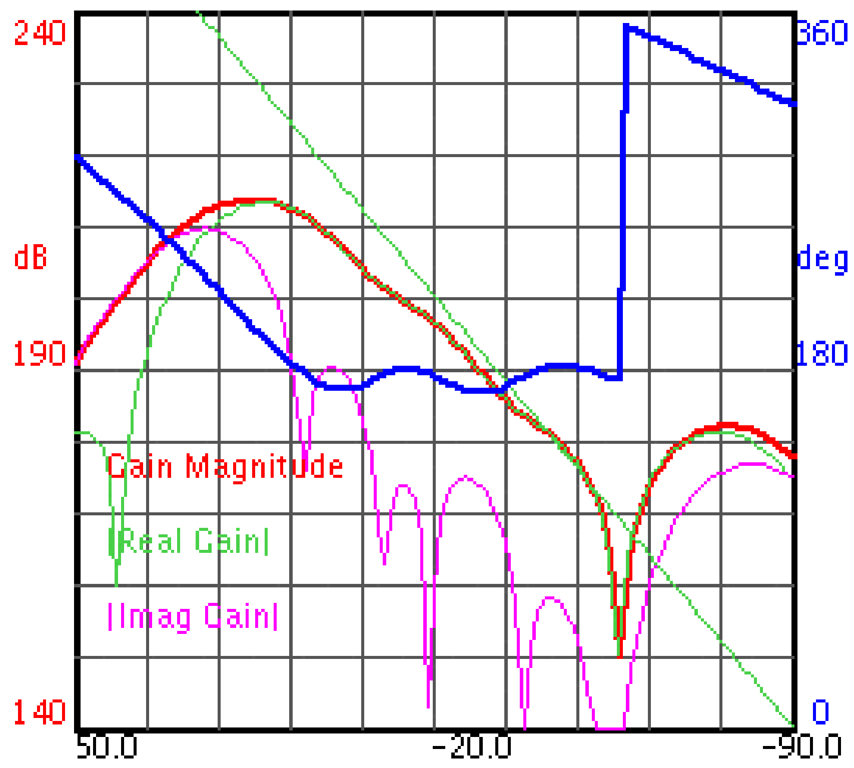
Ψ is local beam density

F is local kicker voltage

- ⇒ Cooling term α FΨ
- ⇒ Diffusive beam heating α F^2 Ψ

- ⇒ As density increases (core), necessary to decrease kicker voltage (system gain) so that cooling term > diffusive heating term

- ⇒ Maximum gain for given stack size



Design and Simulation Performance

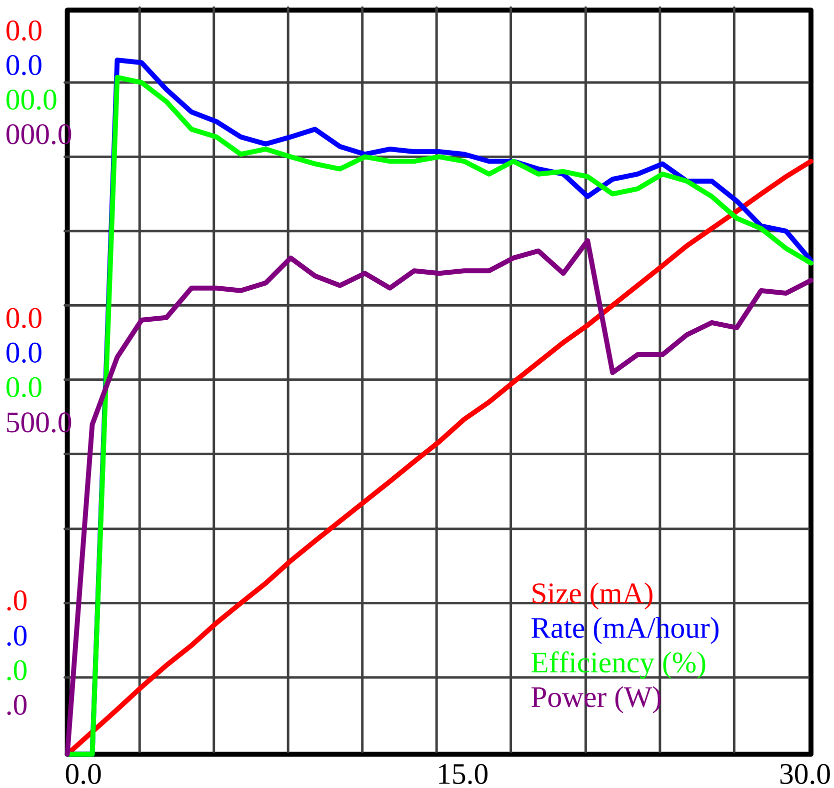
- Design:
  - ⇒ Leg 1 pickup at 15 MeV
  (Run IIa: 16 MeV)
  - ⇒ Leg 2 pickup at -8 MeV
  (Run IIa: 0 MeV)
  - ⇒ Gain and phase adjustments
  - ⇒ Core centered at -52 MeV
  (Run IIa: -50 MeV)

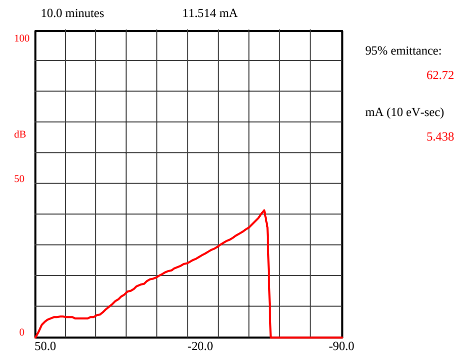
  $\Delta p = 1$ MeV ″ $\Delta x = 0.9$ mm

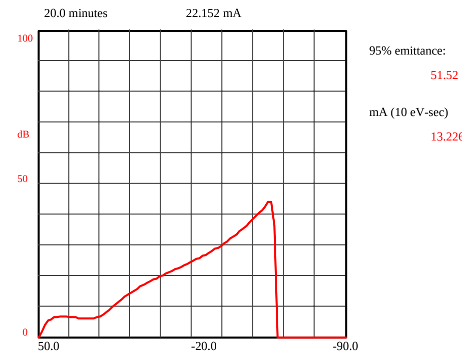
- Simulation of 30 minutes:
  - ⇒ ~82 mA/hour input
  - ⇒ 6 and 8 MeV buckets
  - ⇒ 2 second cycle time
  - ⇒ Dropoff at 13.6 MeV (could be optimized)
  - ⇒ RF phase displace all beam from dropoff + height by 2*height

Simulation Performance
8 MeV bucket

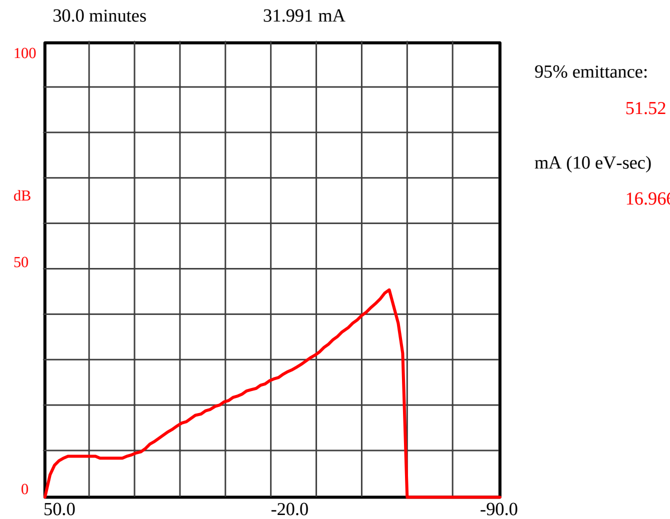
Paul Derwent
7-Dec-01







Mean Rate: 64.3 mA/hour
Efficiency: 79%
Mean Power: 1853 W



Simulation Performance
6 MeV bucket

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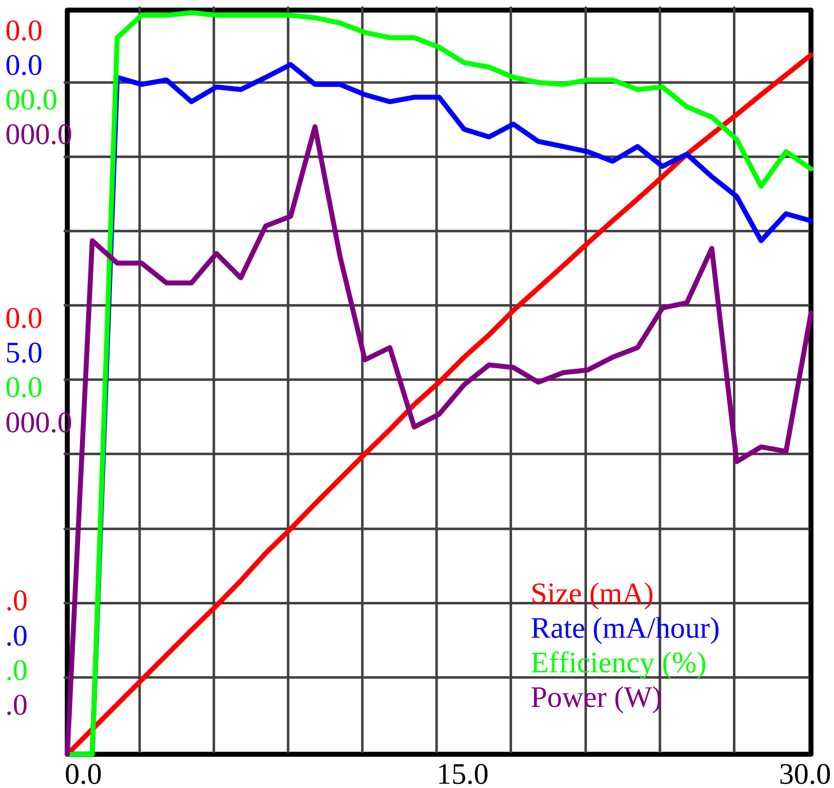

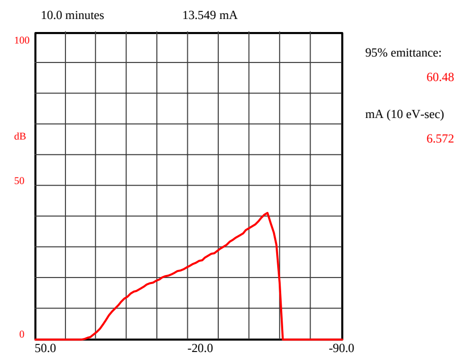

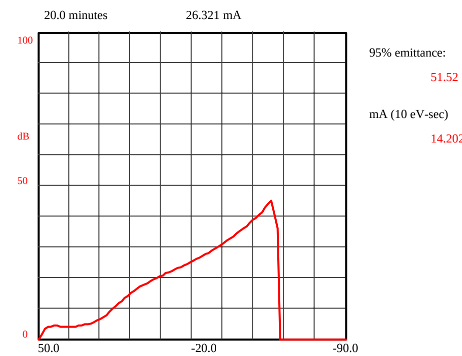

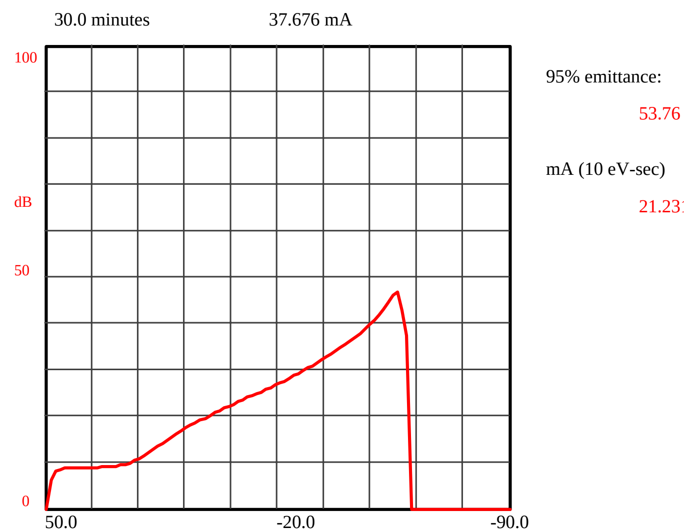

Mean Rate:	75.7 mA/hour
Efficiency:	92.7%
Mean Power:	1150 W

Conclusions

- Bunch Rotation and Debuncher momentum cooling can achieve necessary momentum width
- Stack 75 mA/hour for 30 minutes with 2 sec rep rate and 6 MeV width
- Simulate extraction cycle and performance for next 30 minutes

Time	mA 10 eV-sec (6 MeV)	mA 10 eV-sec (8 MeV)
10 minutes	6.6	5.4
20 minutes	14.2	13.2
30 minutes	21.2	17.0